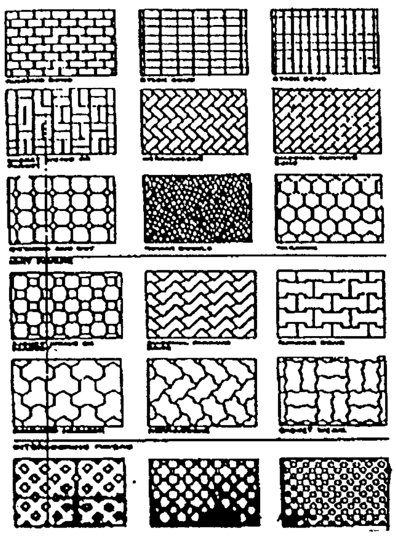
"Walking is nothing more than the successive loss and recovery of balance."
--The Magic of Walking
Aaron Sussman and Ruth Goode

*The landmark Americans with Disabilities Act (ADA), enacted on July 26, 1990, provides comprehensive civil rights protections to individuals with disabilities in the areas of employment (title I), State and local government services (title II), public accommodations and commercial facilities (title III), and telecommunications (title IV). Both the Department of Justice and the Department of Transportation in adopting standards for new construction and alterations of places of public accommodation and commercial facilities covered by title III and public transportation facilities covered by title II of the ADA, have issued implementing rules that incorporate the **Americans with Disabilities Act Accessibility Guidelines (ADAAG)**, developed by the Access Board.*

*For ease in reference, the **ADAAG** text and figures discussed in this Bulletin are reproduced in the sidebars, along with other illustrative material.*

U.S. Architectural and Transportation Barriers Compliance Board



BULLETIN #4: SURFACES

Why are surface characteristics specified?

Over twenty-seven million Americans report some difficulty in walking. Of these, eight million have a severe limitation; one-fifth of this population is elderly. Ambulatory persons with mobility impairments--especially those who use walking aids--are particularly at risk of slipping and falling even on level surfaces. Preliminary research conducted for the Access Board in 1990 through the Pennsylvania Transportation Institute at The Pennsylvania State University compared the slip-resistance needs of persons with mobility impairments and those without disabilities walking on level and ramped surfaces both indoors and out. Findings from this limited human-subject testing confirmed that individuals who have gait and mobility disabilities make greater demands on the walking surfaces of floors, ramps, and walkways. The information in this Bulletin was derived from this and other research in order to provide designers with an understanding of the variables that affect the measurement and performance of materials specified for use on walking surfaces.

What surface characteristics are required of an accessible route?

The Americans with Disabilities Act Accessibility Guidelines *(ADAAG)* requires only that newly-constructed or altered ground and floor

Appendix to 28 CFR Part 36 - Standards for Accessible Design Americans with Disabilities Act Accessibility Guidelines for Buildings and Facilities. 3.5 Definitions.
Accessible Route.
A continuous unobstructed path connecting all accessible elements and spaces of a building or facility. Interior accessible routes may include corridors, floors, ramps, elevators, lifts, and clear floor space at fixtures. Exterior accessible routes may include parking access aisles, curb ramps, crosswalks at vehicular ways, walks, ramps, and lifts.

4. ACCESSIBLE ELEMENTS AND SPACES: SCOPE AND TECHNICAL REQUIREMENTS.
4.1 Minimum Requirements.
4.1.1 Application.
(1) General. *All areas of newly designed or newly constructed buildings and facilities required to be accessible by 4.1.2 and 4.1.3 and altered portions of existing buildings and facilities required to be accessible by 4.1.6 shall comply with these guidelines, 4.1 through 4.35, unless otherwise provided in this section or as modified in a special application section.*

4.1.2 Accessible Sites and Exterior Facilities: New Construction. *An accessible site shall meet the following minimum requirements:*
(1) *At least one accessible route complying with 4.3 shall be provided within the boundary of the site from public transportation stops, accessible parking spaces, passenger loading zones if provided, and public streets or sidewalks, to an accessible building entrance.*
(2) *At least one accessible route complying with 4.3 shall connect accessible buildings, accessible facilities, accessible elements, and accessible spaces that are on the same site.*
(3)...
(4) Ground surfaces along accessible routes and in accessible spaces shall comply with 4.5.

surfaces of accessible routes on sites and in buildings and facilities be *stable, firm, and slip-resistant.* No standards or methods of measurement are specified in scoping or technical provisions, although the Appendix to *ADAAG* contains advisory recommendations for slip resistance values derived from Board-sponsored research. Because the sample size was small, the testing method unique, and the findings not yet corroborated by other research, the suggested values have not been included in the body of *ADAAG* and should not be construed as part of the regulatory requirements for entities covered by titles II and III of the ADA.

However, other regulations, such as those imposed by OSHA in the interests of worker safety, or design and testing standards applied by state, local, or industry mandate, such as certain ASTM (American Society of Testing and Materials) procedures, may require specific values or ranges of slip resistance.

A *stable* surface is one that remains unchanged by contaminants or applied force, so that when the contaminant or force is removed, the surface returns to its original condition. A *firm* surface resists deformation by either indentations or particles moving on its surface. A *slip-resistant* surface provides sufficient frictional counterforce to the forces exerted in walking to permit safe ambulation.

Because of the great number of variables that affect the performance of a given walking surface--its slope and cross-slope, its material, texture and finish, the presence of moisture or contaminants, the material that contacts it and the method of ambulation--no single set of technical specifications or measurement standards can encompass all criteria that contribute to the safety of a walking surface.

Only slip resistance has a commonly applied unit of measurement--the coefficient of friction, which may be measured as static (at rest) or dynamic (in motion). Its calculation is complex and the methods and equipment of its measurement vary. Affected industries--floor finishes, ceramic tile, plumbing fixtures--each employ a different testing methodology in designating the slip resistance of their products. The static coefficients of friction measured according to the four major ASTM-standard testing procedures have never been correlated by research, although a considerable body of data exists.

What is slip resistance?

In its simplest sense, a slip resistant surface is one that will permit an individual to walk across it without slipping. Contrary to popular belief, however, some slippage is in fact necessary for walking, especially for persons with restricted gaits who may drag their feet slightly. While increasing the slip-resistance of a surface is desirable within certain limits, a very high coefficient of friction may actually hinder safe and comfortable ambulation by persons with disabilities. In fact, a truly non-slip surface could not be negotiated.

While visual inspection can provide some information about a surface such as its degree of cleanliness, whether it is wet or dry, and even the type or texture it exhibits, it cannot provide sufficiently accurate information about a surface to be used in design.

Even clean, dry surfaces with readily-apparent texture will not always be slip resistant. Materials which might be suitable for level surfaces may be inappropriate for sloping surfaces; materials specified for dry conditions may be unsafe when it rains; a leather shoe may perform poorly on smooth dry surfaces yet provide adequate traction when wet. The presence of moisture or other contaminants, the characteristics of the shoe sole or crutch tip making contact, the direction (uphill and downhill effects differ) and slope of travel all will affect the slip resistance of installed surfaces. It is this interaction of material characteristics and human responses which fully characterizes slip resistance.

4.1.3 Accessible Buildings: New Construction. Accessible buildings and facilities shall meet the following minimum requirements:
***(1)** At least one accessible route complying with 4.3 shall connect accessible building or facility entrances with all accessible spaces and elements within the building or facility.*
***(3)** Ground and floor surfaces along accessible routes and in accessible rooms and spaces shall comply with 4.5.*

How is slip resistance measured?

The basic components of slip resistance are illustrated in the sidebar. In illustration 1, F_A represents the minimum tangential force necessary to initiate sliding of a body over the surface; F_B is the body gravity force. The coefficient of friction between the two surfaces is the ratio of the horizontal and vertical forces required to move one surface over another to the total force pressing the two surfaces together.

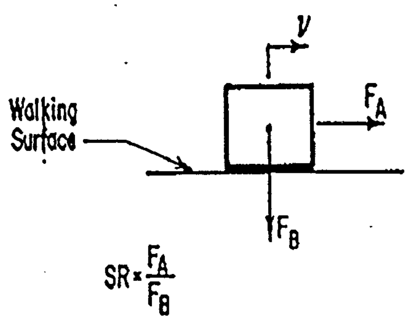


Illustration 1

Illustration 2 demonstrates the three critical stages in an individual's gait: 1) touchdown, 2) full load, and 3) push-off. The small arrows represent the magnitude and direction of the contact forces. In order to avoid slippage while walking, the horizontal and vertical forces applied by the individual must be resisted by forces acting against the foot as it contacts the walking surface. The definitive component of this resisting force--and the variable most subject to manipulation--is the coefficient of friction of the surface material. Consider, for example, an icy surface with a negligible coefficient of friction. A runner whose forward motion applies a substantial horizontal force will slip--and probably fall--on such a surface. A more careful pedestrian may be able to limit his horizontal force contribution so that it balances the available frictional resistance of the ice and thus cross it safely. Adding sand to the icy surface will increase its coefficient of friction and allow for a more standard gait. Once the ice has melted, the higher coefficient of friction of the newly-exposed surface will offer sufficient resisting force to permit the runner to speed across it without incident.

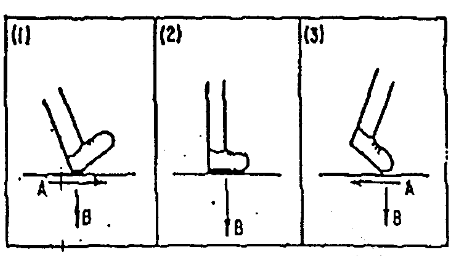


Illustration 2

The *dynamic* coefficient of friction varies in a complex and non-uniform way. Although it can be calculated and modeled in the laboratory using sophisticated computer programs, the more straighforward measurement of the *static* coefficient of friction provides a reasonable approximation of the slip resistance of most surfaces and is the method most appropriate for evaluating surface materials and finishes.

A variety of devices are available for such measurements. The most common device, the James machine, was developed in the early 1940s and was the testing device specified by the Underwriters Laboratory (UL) shortly thereafter when it established--from laboratory test data corroborated by field experience--a minimum value of 0.5 for the static coefficient of friction for floor polish bearing the UL seal. Since then, 0.5 has become the commonly-accepted threshold for classifying slip resistance in products. Furthermore, the James machine is the recognized test method and the 0.5 value (when measured by this tester) is the recognized minimum criterion for slip-resistant walking surfaces in courts of law in the United States.

Measurement by the James machine, utilizing a leather sensor, is the only method appropriate for assessing surfaces and products against the 0.5 UL standard for static coefficient of friction. Using a different sensor material, even if measured by the James machine, will give a different reading for the same surface material.

This is a significant point. An informal comparison of data collected under three different research protocols, involving four different friction-testers and four different shoe sensor materials, all applied to the same 8-inch by 8-inch ceramic tile surface, resulted in thirty readings--ranging from a low of .29 to a high of .99--for its static coefficient of friction. Even limiting values to those measured by the James machine but using both leather and Neolite sensor material resulted in a range of 0.57 (leather) to 0.79 (Neolite) for the same surface being tested.

It is impossible to correctly specify a slip-resistance rating without identifying the testing method, tester, and sensor material to be used in evaluating the specified product and equally invalid to compare values obtained through one methodology to those resulting from different testing protocols. Because a consensus test protocol has not yet been identified, the Access Board did not specify a value or testing method for determining the coefficient of friction along an accessible route.

The James machine continues to be a laboratory mainstay, but is not portable and thus cannot be used in field testing. In order to measure the slip-resistance of surfaces already in place, researchers at The Pennsylvania State University evaluated three portable testers:

- the NBS-Brungraber Tester (also known as the Mark I Slip Tester),
- the PTI (Pennsylvania Transportation Institute) Drag Sled Tester, and
- the Horizontal Pull Slipmeter.

Study criteria included *relevance* (the measuring results should correlate in a known and constant manner with human perception of the surface slipperiness); *versatility* (accurate measurements of slip resistance must be possible on various types of surfaces and under diverse conditions); *sensitivity to measuring technique* (the difference between measurements performed on the same surface and under the same conditions by different persons should be minimal), and *repeatability* (tests of the same surfaces under the same conditions should be consistent over time). In addition, the reliability and precision of the testers were assessed.

Based on the results of this study, the NBS-Brungraber Tester was recommended as the best portable device currently available for measuring slip resistance under dry conditions on all but carpeted surfaces. Easy to use, the NBS-Brungraber testing procedure can be mastered in 30 minutes. It measures the static coefficient of friction between a representative sample of shoe sole material and a flooring

4.5 Ground and Floor Surfaces.

4.5.1 General. *Ground and floor surfaces along accessible routes and in accessible rooms and spaces including floors, walks, ramps, stairs, and curb ramps, shall be stable, firm, slip-resistant, and shall comply with 4.5.*

4.5.2 Changes in Level. *Changes in level up to 1/4 in (6 mm) may be vertical and without edge treatment. Changes in level between 1/4 in and 1/2 in (6 mm and 13 mm) shall be beveled with a slope no greater than 1:2. Changes in level greater than 1/2 in (13 mm) shall be accomplished by means of a ramp that complies with 4.7 or 4.8.*

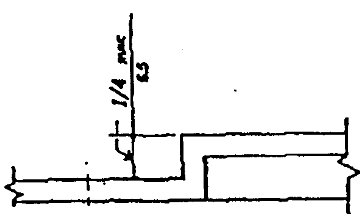


Figure 7(c)
Changes in Level

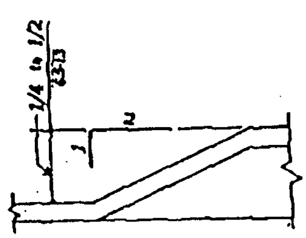


Figure 7(d)
Changes in Level

4.5.3 Carpet.
If carpet or carpet tile is used on a ground or floor surface, then it shall be securely attached; have a firm cushion, pad, or backing, or no cushion or pad; and have a level loop, textured loop, level cut pile, or level cut/uncut pile texture. The maximum pile thickness shall be 1/2 in (13 mm) (see Fig. 8(f)). Exposed edges of carpet shall be fastened to floor surfaces and have trim along the entire length of the exposed edge. Carpet edge trim shall comply with 4.5.2.

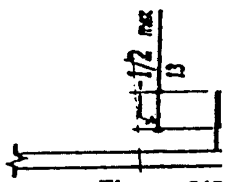


Figure 8(f)
Carpet Pile Thickness

4.5.5 Gratings.
If gratings are located in walking surfaces, then they shall have spaces no greater than 1/2 in (13 mm) (see Fig. 8(g)) wide in one direction. If gratings have elongated openings, then they shall be placed so that the long dimension is perpendicular to the dominant direction of travel. *(see Fig. 8(h)).*

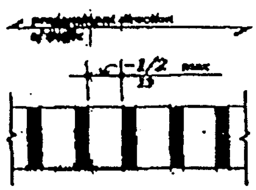


Figure 8(g)
Gratings

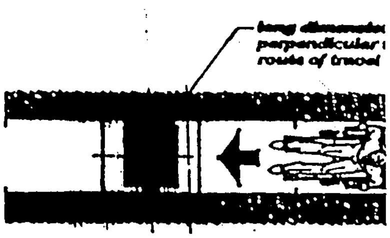


Figure 8(h)
Grating Orientation

surface. The result from the recording shaft is converted into an equivalent value of static coefficient of friction by means of a calibration chart supplied with the tester.

The PTI Drag Sled Tester performed well in the tests but was not commercially available at the time of completion of the report. The Horizontal Pull Slipmeter, which proved to be an excellent device for laboratory measurements of slip resistance, did not produce satisfactory results in field measurements. Detailed information about the three testers, including cost and availability, can be obtained by contacting the following persons:

• **NBS-Brungraber Tester**	Robert J. Brungraber, PhD 409 South 21st Street Lewisburg, PA 17837 (717) 524-0852
• **PTI Drag Sled Tester**	Bohdan T. Kulakowski, PhD The Pennsylvania State University 201 Research Office Building University Park, PA 16802 (814) 863-1893
• **Horizontal Pull Slipmeter**	Whitely Industries 939 C East Street Tewksbury, MA 01876 (508) 640-1177

Other portable testers that may be used to measure static coefficient of friction include the Mark II Slip Tester (available from the manufacturer of the NBS-Brugraber Tester) and the Model 80 Tester:

• **Model 80 Tester**	Donald C. Meserlian, PE Technical Products Company 264 Park Avenue North Caldwell, NJ 07006 (201) 228-2258

It is important to maintain the testing device in good working order and to calibrate it periodically. Changes over time in the measured value of a coefficient of friction can occur due to wear of the machine sensor shoe as well as to changes in the floor material and finish.

The slip resistance of indoor and outdoor walking surfaces already in place can be measured with one of the portable testers listed in this Bulletin in order to monitor the process of wear and polishing of walking surfaces. An initial reading of the coefficient of friction taken after flooring has been placed and finished will provide a baseline for future comparisons. However, do not attempt to compare such readings to the UL 0.5 coefficient of friction standard or to a

APPENDIX
This appendix contains material of an advisory nature and provides additional information that should help the reader to understand the minimum requirements of the guidelines or to design buildings or facilities for greater accessibility. The paragraph numbers correspond to the sections or paragraphs of the guideline to which the material relates and are therefore not consecutive (for example, A4.2.1 contains additional information relevant to 4.2.1). Sections of the guidelines for which additional material appears in this appendix have been indicated by an asterisk. Nothing in this appendix shall in any way obviate any obligation to comply with the requirements of the guidelines itself.

A.4.5 Ground and Floor Surfaces.
A4.5.1 General.
People who have difficulty walking or maintaining balance or who use crutches, canes, or walkers, and those with restricted gaits are particularly sensitive to slipping and tripping hazards. For such people, a stable and regular surface is necessary for safe walking, particularly on stairs. Wheelchairs can be propelled most easily on surfaces that are hard, stable, and regular. Soft loose sand or gravel, wet clay, and irregular surfaces such as cobblestones can significantly impede wheelchair movement.

Slip resistance is based on the frictional force necessary to keep a shoe heel or crutch tip from slipping on a walking surface under conditions likely to be found on the surface. While the dynamic coefficient of friction during walking varies in a complex and non-uniform way, the static coefficient of friction, which can be measured in several ways, provides a close approximation of the slip resistance of a surface. Contrary to popular belief, some slippage is necessary to walking, especially for persons with restricted gaits; a truly "non-slip" surface could not be negotiated.

manufacturer's slip resistance values unless the same testing methodology, machine, and sensor material was used in each instance.

What values are recommended for ground and floor surfaces along an accessible route?

The surfaces of the accessible route on a site or within a building or facility must be designed to provide slip-resistant locomotion for both level and inclined travel by persons with disabilities. Research findings suggest that such surfaces should have a slip resistance somewhat higher than might be provided for individuals without disabilities.

In the study sponsored by the Access Board, laboratory measurements from a Kistler force plate and computer analysis of the gaits of persons with mobility impairments (including crutch users and above- or below-knee amputees using artificial limbs) and persons without disabilities graphed the *dynamic* coefficients of friction necessary for safe ambulation. The m-shaped curves that resulted gave a range of values from touch-down to take-off (control group: 0.2-0.3; persons with disabilities 0.7-1.0). Wheelchair users were tested through a full cycle of push and recovery (0.5-0.7).

Correlating these values with a single *static* coefficient of friction (the relationship is complex and non-linear) is inexact and involves some approximation in order to facilitate simplified field testing procedures. In the Access Board research, the static coefficients of friction for a variety of common indoor and outdoor surfacing materials were measured in place using the NBS-Brungraber Tester with a silastic sensor material. Although this machine operates on a principle similar to that of the James machine, the use of a non-standard silastic sensor (instead of the leather required by the protocol for the UL standard) results in significantly higher values for the coefficient of friction of the surfaces being measured. As no correlation was made to any other standards or methodologies in the research, the values for coefficient of friction cannot be compared.

Researchers' recommendations for a static coefficient of friction for surfaces along an accessible route, when measured by the NBS-Brungraber machine using a silastiac sensor shoe, were approximately 0.6 for a level surface and 0.8 for ramps. These values are included in the advisory material in the Appendix to *ADAAG*, but are not in any way mandatory.

What materials may satisfy *ADAAG* requirements?

In new construction and alterations, surface materials must be specified to be slip-resistant. If there is a choice between flooring materials otherwise suitable for a particular application, we recommend choosing the material with the higher coefficient of friction, particularly for ramps.

Materials that might be appropriate for ramps and level surfaces include concrete wood float surfaces, asphalt, and some types of carpets and resilient tiles. Materials which might be expected to be satisfactory for level surfaces, but which might not be appropriate for ramps, include concrete metal trowelled surfaces, ceramic tile, hardwood and flagstone. These finishes, tested during the Access Board research project, yielded coefficients of friction that fell within the recommended ranges for accessible routes.

The Occupational Safety and Health Administration recommends that walking surfaces have a static coefficient of friction of 0.5. A research project sponsored by the Architectural and Transportation Barriers Compliance Board (Access Board) conducted tests with persons with disabilities and concluded that a higher coefficient of friction was needed by such persons. A static coefficient of friction of 0.6 is recommended for accessible routes and 0.8 for ramps.

It is recognized that the coefficient of friction varies considerably due to the presence of contaminants, water, floor finishes, and other factors not under the control of the designer or builder and not subject to design and construction guidelines and that compliance would be difficult to measure on the building site. Nevertheless, many common building materials suitable for flooring are now labeled with information on the static coefficient of friction. While it may not be possible to compare one product directly with another, or to guarantee a constant measure, builders and designers are encouraged to specify materials with appropriate values. As more products include information on slip resistance, improved uniformity in measurement and specification is likely.

Cross slopes on walks and ground or floor surfaces can cause considerable difficulty in propelling a wheelchair in a straight line.

However, not all products of the type mentioned may provide the desired slip resistance and many other materials can be expected to be suitable even though they are not included here. For example, some types of materials for which the coefficient of friction is low, are available--or can be treated--with finishes that increase slip resistance.

Products or finishes applied to surfaces after installation are not covered by *ADAAG*, but may fall under the Department of Justice (DOJ) regulation governing the maintenance of accessible features. Moisture and debris contamination adversely affect the surface slip resistance of most installed finishes. While floor treatments are available that will increase the coefficient of friction of a walking surface, some products or furnishings, such as furniture wax overspray or loose throw rugs, may reduce slip resistance significantly. Others--for example, walkoff mats placed on lobby floors during rainy weather--do much to reduce the chance of slipping on a wet floor. Such mats are not considered carpets within the meaning of *ADAAG 4.5.3.*

What other surface considerations affect wheelchair travel?

In addition to slip resistance requirements, wheelchair users are affected by the **rolling resistance** of the surface of the floor and--on exterior surfaces--by **cross slope**. If the rolling resistance of flooring is high, wheelchair users must avoid those areas or expend extra energy maneuvering across the surface. In a limited study of wheelchair rolling resistance, the force needed to traverse four different surfaces was measured: concrete, linoleum, low-pile carpet (loop, 0.1-inch pile height, 10 stitches/inch, 16-ounce face weight excluding backing and glue, on jute), and high-pile carpet (cut, 0.5-inch pile height, 10 stitches/inch, 40-ounce face weight excluding backing and glue, on ActionBac).

Although the study was not intended to be comprehensive, the results provide some guidance in selecting carpet. With the force needed to traverse bare concrete as a baseline, the increase in force needed to cross each surface was measured to be: +3% for linoleum; +20% for low-pile carpet, and +62% for high-pile carpet. From these results it appears that linoleum and concrete equally require minor effort; low-pile carpet requires a noticeable, though moderate, increase in effort; and high-pile carpeting requires a significant increase in effort. Although the slip resistance ratings of carpet fall within the recommended ranges for use on ramps, its rolling resistance makes most types an inappropriate finish for sloped surfaces.

Exterior ramps and walks will generally be constructed with a cross-slope (perpendicular to the direction-of-travel slope) in order to provide positive drainage. Because the effects of cross-slope are particularly difficult for persons using wheelchairs--particularly along a steep running slope--*ADAAG* provisions limit accessible routes to a 2% cross-slope.

A4.5.3 Carpet.
Much more needs to be done in developing both quantitative and qualitative criteria for carpeting (i.e., problems associated with texture and weave need to be studied). However, certain functional characteristics are well established. When both carpet and padding are used, it is desirable to have minimum movement (preferably none) between the floor and the pad and the pad and the carpet which would allow the carpet to hump or warp. In heavily trafficked areas, a thick, soft (plush) pad or cushion, particularly in combination with long carpet pile, makes it difficult for individuals in wheelchairs and those with other ambulatory disabilities to get about. Firm carpeting can be acheived through proper selection and combination of pad and carpet, sometimes with the elimination of the pad or cushion, and with proper installation. Carpeting designed with a weave that causes a zig-zag effect when wheeled across is strongly discouraged.

What other considerations are significant for persons with disabilities?
Materials such as gravel, wood chips, or sand, often used for outdoor walkways, are neither firm nor stable, nor can they generally be considered slip-resistant. Thus, walks surfaced in these materials could not constitute an accessible route. However, some natural surfaces, such as compacted earth, soil treated with consolidants, or materials stabilized and retained by permanent or temporary geotextiles, gridforms, or similar construction may perform satisfactorily for persons using wheelchairs and walking aids.

ADAAG also contains provisions that limit surface discontinuities along an accessible route, including elevator cab leveling tolerances at landings, gaps between car and platform in transit facilities, the size and orientation of openings in walkway gratings, the profile of doorway thresholds, and the pile height and attachment of carpeting. *ADAAG 4.5.3* specifies that carpet and carpet tile be securely attached. This provision does not require that each tile--or the entire carpet or pad--be adhered to the floor surface provided the method of securement results in a surface that is stable, firm, and slip-resistant and does not pose a tripping hazard.

DOJ
28 CFR Part 36
§ 36.211 Maintenance of Accessible Features.
(a) A public accommodation shall maintain in operable working condition those features of facilities and equipment that are required to be readily accessible to and usable by persons with disabilities by the Act or this part.
(b) This section does not prohibit isolated or temporary interruptions in service or access due to maintenance or repairs.

The *Staircase, Studies of Hazards, Falls and Safer Design*, by John Templer (The MIT Press, Cambridge, MA 1992) contains (Chapter 3) an excellent discussion of slip resistance on ramps that will be of interest to designers and specifiers.

U. S. Architectural and Transportation Barriers Compliance Board
The Access Board / 1331 F St. NW #1000 / Washington, DC 20004
TEL: (800)USA-ABLE (202)272-5434 TDD: (202)272-5449